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July 1995

Comparison Between Finite Element Study and Simplified Analysis of Levee Underseepage

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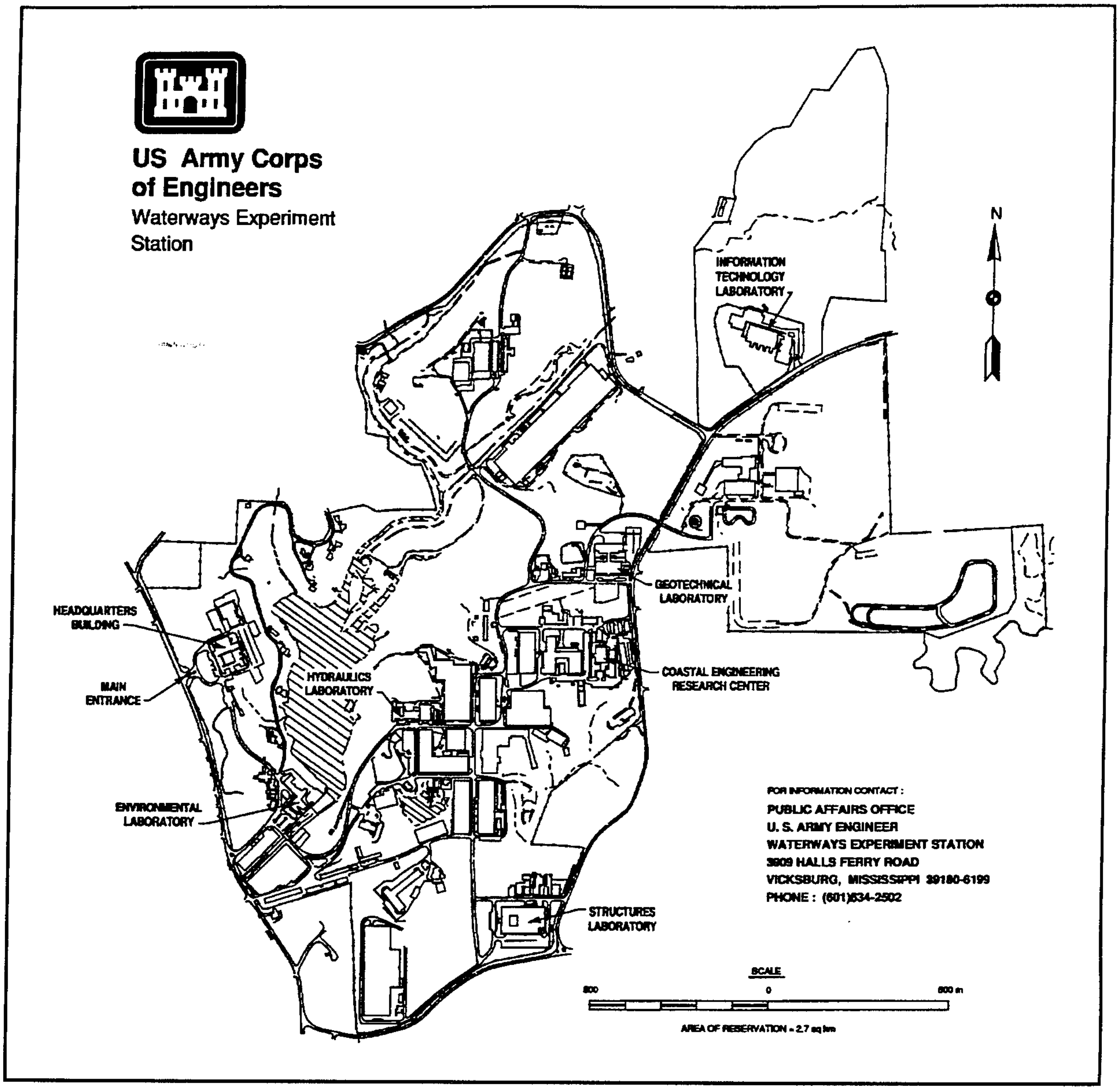

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Contents

List of Figures

Preface

This report describes a study to compare results of using computer programs, LEVSEEP and LEVEEMSU, and finite element program SEEP for a prototypical levee section located in Magnolia, Ohio, within the Huntington District of the Corps of Engineers. The levee section chosen for analysis is described in detail in this report. Results presented in this study illustrate the effect of variations in the ratio of permeability of the foundation (k_f) to the permeability of the blanket (k_b) on the flow predictions, the influence of introducing anisotropic conditions on flow domain, and variation in the predicted hydraulic gradients in relation to the analysis method. Analysis results are reported in terms of landside exit hydraulic gradients and permeability ratios.

Work accomplished during corrections, verification, and consultation was funded under the Numerical Model Maintenance Program from Headquarters, U.S. Army Corps of Engineers (HQUSACE), and from the Huntington District for the Magnolia, OH, levee case study.

Work in this report was performed by Dr. M. A. Gabr of West Virginia University, Mr. Anthony L. Brizendine of Fairmont State College, and Mr. Hugh M. Taylor, Jr., Soils Mechanics Branch (SMB), Soil and Rock Mechanics Division (S&RMD), Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES). Mr. W. L. Hanks, SMB, provided automated drafting and editorial support.

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During the preparation and publication of this report, the Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

1 Introduction

Background on Levees and Underseepage

Levees are earth structures constructed to provide flood protection during and after high-water events. They are utilized for the protection of agricultural land from floodwater and flood protection of industrial, commercial, and residential facilities. A major concern associated with these levees is the underseepage through the foundations on which they are constructed. In situations where flood-control levees are constructed on pervious foundations, seepage beneath a given levee can result in failure during flood periods. Such a failure develops because of excessive uplift pressures, piping, and subsurface erosion.

In general, most of the Corps criteria for design of levees were developed in the 1940s and 1950s. There has been an emerging concern that Corps procedures and criteria may be overly conservative in many cases and unconservative in others. Overconservative design may necessitate the implementation of costly control measures where they may not be needed. Unconservative design is usually evidenced through the failure of analysis to predict excess gradients at locations where sand boils may occur and can be detrimental.

Levee underseepage was identified by field personnel of the Army Corps of Engineers to be one of the high-priority soils-related problems to be addressed in the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program (Scanlon et al. 1983). A Levee Underseepage Workshop for the REMR program was held at the U.S. Army Corps of Engineers, Waterways Experiment Station (WES), on 10 April 1984 to establish research needs related to levee underseepage control. Representatives from the Rock Island, St. Louis, Memphis, and Vicksburg Corps of Engineers' Districts attended. One research task identified was comparing predicted levee underseepage conditions to observed performance. Data collected in the past two decades on the performance of levees during major flood events can be used for this purpose.

A review of underseepage analysis procedures was prepared by Wolff (1986). Wolff (1986) noted that the Corps analysis and design procedures required a high level of judgment to formulate geometric and geologic conditions. In particular, while actual soil profiles and topography are often irregular, current Corps manual procedures require the specification of horizontally leveled topography with uniform thicknesses of the soil layers. While one very important aspect of the levee design involves developing an accurate characterization of the site conditions, it is not uncommon for two designers to arrive at different characterizations for the same site.

The computer programs LEVSEEP and LEVEEMSU were developed as part of the Corps approach to facilitate and simplify analyses of levee underseepage and assist in evaluating inconsistencies between predicted and actual levee performance. The computer program LEVSEEP is based on the analytical Method of Fragments while LEVEEMSU is based on one-dimensional simplification of the flow domain using the finite difference method.

Analysis in this report include comparative results from LEVSEEP, LEVEEMSU, and the finite element programs PCSEEP and SEEP. While LEVSEEP and LEVEEMSU are well-documented computer programs, this study will provide further evaluation of analysis schemes implemented in these programs. The well-documented site of Magnolia Levee is used for this comparative study. The finite element computer program SEEP, chosen for such an analysis, was developed by Wong and Duncan (1985). Seepage models in SEEP include saturated-free surface or confined steady-flow problems. PCSEEP (Geo-Slope Programming Limited 1988) is a two-dimensional finite element program for saturated and unsaturated seepage analyses.

Scope

The purpose of this study is to compare results of LEVSEEP, LEVEEMSU, and SEEP for a prototypical levee section located in Magnolia, Ohio, within the Huntington District of the Corps of Engineers. The levee section chosen for analysis is described in detail in this report. Results presented in this study illustrate the effect of variations in the ratio of permeability of the foundation (k_f) to the permeability of the blanket (k_b) on the flow predictions, the influence of introducing anisotropic conditions on flow domain, and variation in the predicted hydraulic gradients in relation to the analysis method. Analyses results are reported in terms of landside exit hydraulic gradients and permeability ratios.

Chapter 2 of the report includes an overview of the three models used in this study. Description of Magnolia Levee reach and its location is presented in Chapter 3. Idealization of analysis cross section and description of analysis cases are presented in Chapter 4. Results are discussed in Chapter 5 with summary and conclusions presented in Chapter 6.

2 Program Descriptions

LEVSEEP

The computer program LEVSEEP was developed to provide an efficient and reproducible means of analyzing levee underseepage. The ability to evaluate underseepage control measures was incorporated into LEVSEEP, as well as the capability for estimating material quantities and cost. The focus of LEVSEEP in this study is on its results being closed form solutions for evaluation of seepage quantities and hydraulic gradients at the landside toe of the levee.

Subsurface conditions in LEVSEEP are modeled as two layers; a semi-pervious top blanket or top stratum of clay, silt, or silty sand overlying a pervious substratum of sand. The rational behind such modeling is that levee sites in alluvial valleys are traditionally modeled as two soil layers. The analysis scheme in LEVSEEP is based on assuming that high-water conditions riverside of the levee result in downward flow through the riverside top blanket, lateral flow through the pervious substratum, and upward flow through the landside top blanket. Given certain conditions of geometry and soil properties, the upward gradient in the landside top blanket can be excessive, and safety against uplift and sand boils are of concern. In cases where calculations indicate that excessive gradients are expected, control measures may be required. These measures are typically landside seepage berms, riverside blankets, cutoffs, or relief wells.

The models developed in Corps publications and incorporated into LEVSEEP make basic assumptions that must be recognized. Those assumptions are as follows:

a. Seepage may enter the pervious substratum at any point in the foreshore (usually at the riverside borrow pit) and/or through the riverside top stratum.

b. Flow through the top stratum is vertical.

c. Flow through the pervious foundation is horizontal.

d. The levee (including impervious or thick berms) and the portion of the top stratum beneath it are impervious.

e. All seepage is laminar.

The procedures for riverside blanket analysis are as presented in Technical Memorandum (TM) 3-424 (U.S. Army Engineer Waterways Experiment Station 1956). LEVSEEP calculates seepage flow and substratum pressure for either physical and geometric properties (initial conditions) or field piezometer readings. It also calculates the effect of various control measures on seepage flow and substratum pressure for those cases for which published Corps procedures exist.

Nine distinct cases based on top stratum conditions are available for calculating initial conditions from physical and geometric properties; the first seven are described in Engineer Manual (EM) 1110-2-1913 (Headquarters, Department of the Army 1978), and the last two are combinations of semipervious and impervious landside and riverside top stratum added for completeness. A listing of those nine cases is as follows:

Case No. 1. No top stratum.

Case No. 2. Impervious top stratum both riverside and landside.

Case No. 3. Impervious riverside top stratum and no landside top stratum.

Case No. 4. Impervious landside top stratum and no riverside top stratum.

Case No. 5. Semipervious riverside top stratum and no landside top stratum.

Case No. 6. Semipervious landside top stratum and no riverside top stratum.

Case No. 7. Semipervious top stratum, both riverside and landside.

Case No. 8. Impervious riverside top stratum (seepage entrance open) and semipervious landside top stratum.

Case No. 9. Semipervious riverside top stratum and impervious landside top stratum.

A thorough discussion of these cases can be found in Technical Report REMR-GT-13 (Cunny, Agostinelli, and Taylor 1989) and EM 1110-2-1913 (Headquarters, Department of the Army 1978).

LEVEEMSU

Compared to LEVSEEP, the computer program LEVEEMSU (Wolff 1989) provides the capability to analyze irregular foundation geometry and nonuniform soil properties. Analysis algorithm implemented in the program is based on solving Bennett's (1946) differential equation for one-dimensional flow. While analytical solutions are suitable for cases with simple geometry and uniform soil properties, numerical methods such as the finite difference method can be used in variable situations. With the use of numerical methods, analyses parameters can be assigned or interpolated at a number of points or nodes; and the differential equation is approximately represented at each node for prediction of flow heads.

With the program LEVEEMSU, the cross section of the levee can be modeled as a one-dimensional domain with a unit width. The one-dimensional seepage flow is assumed to be horizontal in the substratum and vertical in the top blanket; seepage through the levee is not considered. A one-dimensional numerical solution is obtained by considering a line of nodes to represent the foundation substratum and a line of nodes to model the top blanket. The program user describes the foundation geometry using x and y coordinates along a number of vertical sections. The program generates a set of nodes and associated geometry information based on the user input. Dimensions and properties are assumed to vary linearly between nodes. As the piezometric head in the substratum is implied to be constant along any vertical section, each node actually represents the entire thickness of the substratum at the location of the node.

Flow through a representative element of the foundation is lumped at the model nodes for analysis. Continuity requirements are satisfied at each node. The continuity equation is discretized in terms of the piezometric elevation at a given node. Solution is obtained using an iterative technique to develop an estimate for the piezometric head at node locations.

PCSEEP

PCSEEP (Geo-Slope Programming Limited 1988) is a two-dimensional finite element computer program for saturated and unsaturated seepage analyses. The program is formulated for conditions of constant total stress with the assumption that pore pressure remains constant at atmospheric pressure during transient processes. Anisotropic permeability conditions are handled by the program. Boundary conditions can include specified head and/or flux. The program is capable of computing the distribution of pore pressure, hydraulic heads, flow velocities, hydraulic gradients, and total seepage volumes within a flow domain.

SEEP

SEEP is a computer program, written in FORTRAN IV, that employs the finite element method to numerically solve steady-state problems of free surface or confined flow of groundwater, either in a two-dimensional or axisymmetric porous medium. The current version of the program is derived from the program FREESURF 1, initially coded by Neuman and Witherspoon (1989). The version used for this study was originally coded by Wong under the direction of J. M. Duncan (1985).

SEEP accepts input data defining problem geometry, nodal point and element information, and material types. Boundary conditions and problem type are also specified by the user. SEEP assembles the local and global transmissivity matrices and modifies the boundary conditions for nodal points with fixed heads. Gaussian elimination on the global matrix is performed, and flow at the nodes is computed. SEEP calculates location of the free surface and then resets the mesh for successive iterations. The program repeats this process until the results converge. Isotropic or anisotropic hydrogeologic parameters can be specified within SEEP. Rectangular or triangular elements can be used with specified boundaries as either flow influx or total head.

3 Description of Prototype Levee Reach at Magnolia Levee, Ohio

One reach of Magnolia Levee is selected as the analysis case study to provide comparative results of the three models being used. The prototype reach is identified as having sufficient data to conduct the analysis with foundation conditions appropriate for programs application and illustration. Magnolia Levee is located in the Huntington District. A site location map is presented in Figure 1.

The Magnolia Levee drainage district is located in the Muskingum watershed of southeastern Ohio. The levee is located 6.5 miles (10.5 km) east of Bolivar dam on Sandy Creek of the Tuscarawas River, a tributary of the Muskingum River. The levee protects the town of Magnolia, Ohio. The total length of the levee is 4,877 ft (1,486.5 m) with crest elevations that vary between el 966[1] and el 976. The levee is monitored by 13 open tube piezometers that are strategically located along the length of the embankment. The levee has no relief wells.

The section analyzed and presented in this study has a two-layer foundation with top stratum, both riverside and landside. A soil profile representative of this section is shown in Figure 2. The site is generally underlain by cohesionless soils that mainly consists of fine to medium sand and gravel. A discontinuous top stratum with a thickness that ranges from 4 to 8 ft (1.22 to 2.44 m) and consists of silt and clay/sandy clay exists at the south reach of the levee east of the intake channel between sta 5+00 and 10+00. Thirteen open tube piezometers (D-1 through D-10, D-3A, D-6A, and D-8A) are monitored to evaluate the pore water conditions in the foundation and embankment of the levee. These piezometers were installed in 1988. The tips of all piezometers were placed above el 931, and therefore Pool of Record (P.O.R.) of 1991, at el 950.1, was the only event during which piezometric responses were

[1] Elevations are in feet mean sea level.

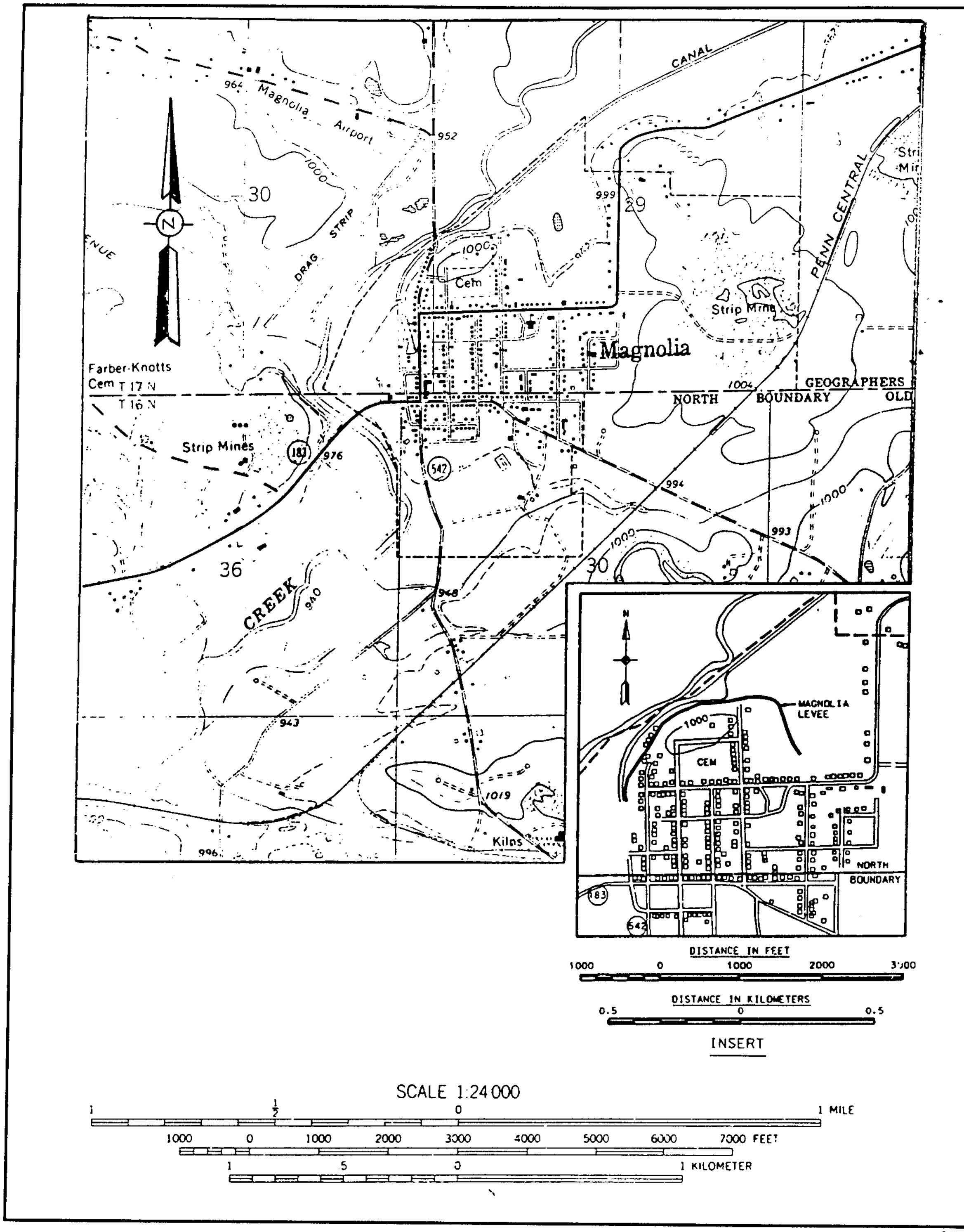

Figure 1. Site location map: Magnolia Levee, Huntington District

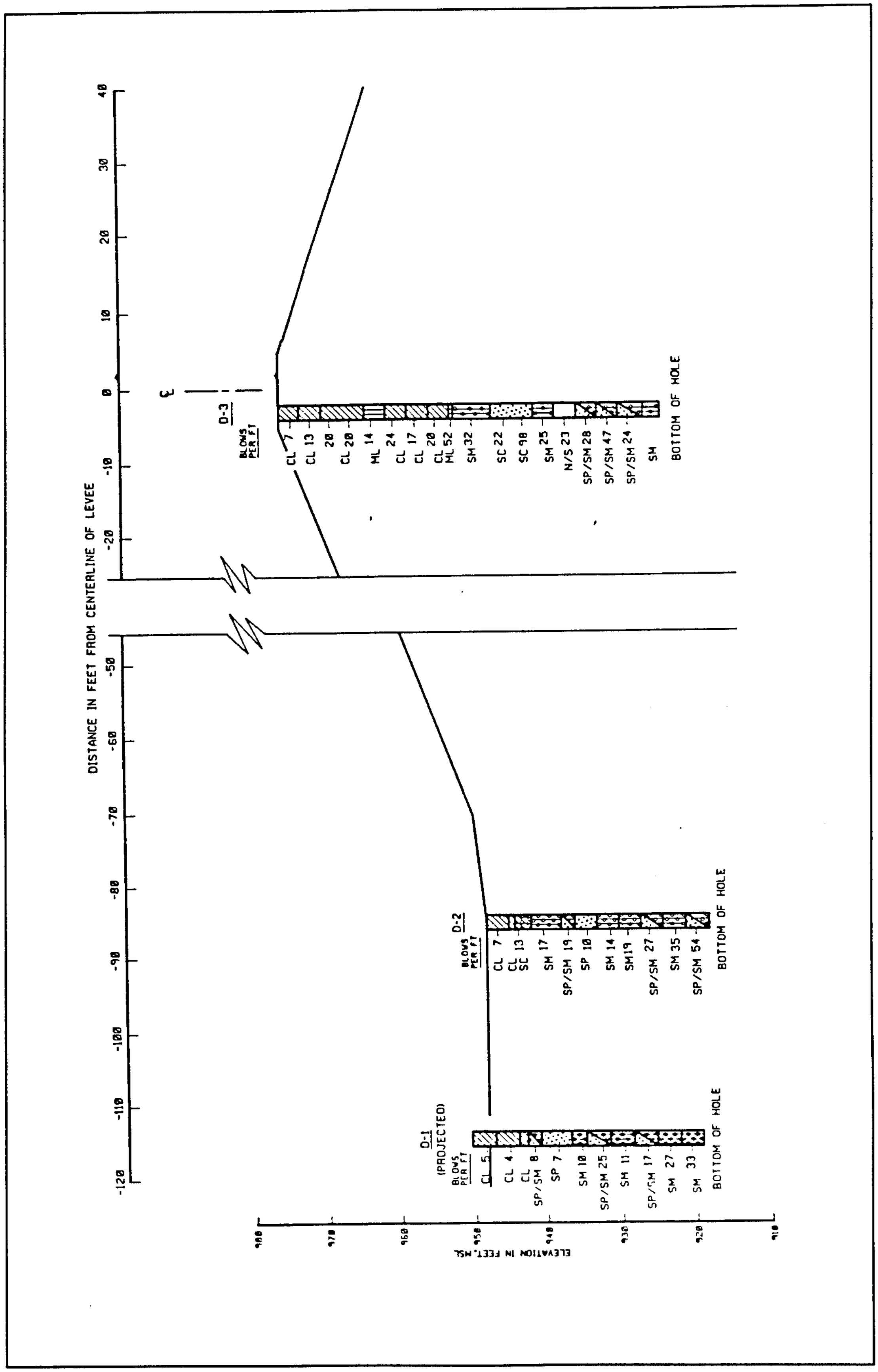

Figure 2. Soil profile between sta 5+00 and sta 10+0

observed. Approximately 16 readings from each piezometer were obtained during this event as presented in the Periodic Inspection Report No. 5, June, 1991. In general, fluctuation in piezometer readings when no water is stored against the levee appears to reflect perched groundwater conditions.

Data from piezometers monitored during the P.O.R. event, which occurred at el 950.1, and with tailwater elevation between el 943 and el 944.7 are presented as Table 1. These data are not used in this study, but presented herein for the sake of completeness.

Table 1
Piezometer Data During the P.O.R. Event (El. 950.1)

Piez.	Piez. Elevation Date: 6/91
D-1	949.3
D-2	948.8
D-3	948.4
D-4	945.5
D-5	944.7
D-6	948.5
D-7	948.7
D-8	946.2
D-9	948.4
D-10	947.0

The typical cross section considered for the analysis of this site is taken at the location of piezometers D-2, D-3, and D-3A and represents the portion of the site where a top blanket was assumed to be 7 ft (2.13 m) thick. Figure 3 provides the piezometer locations.

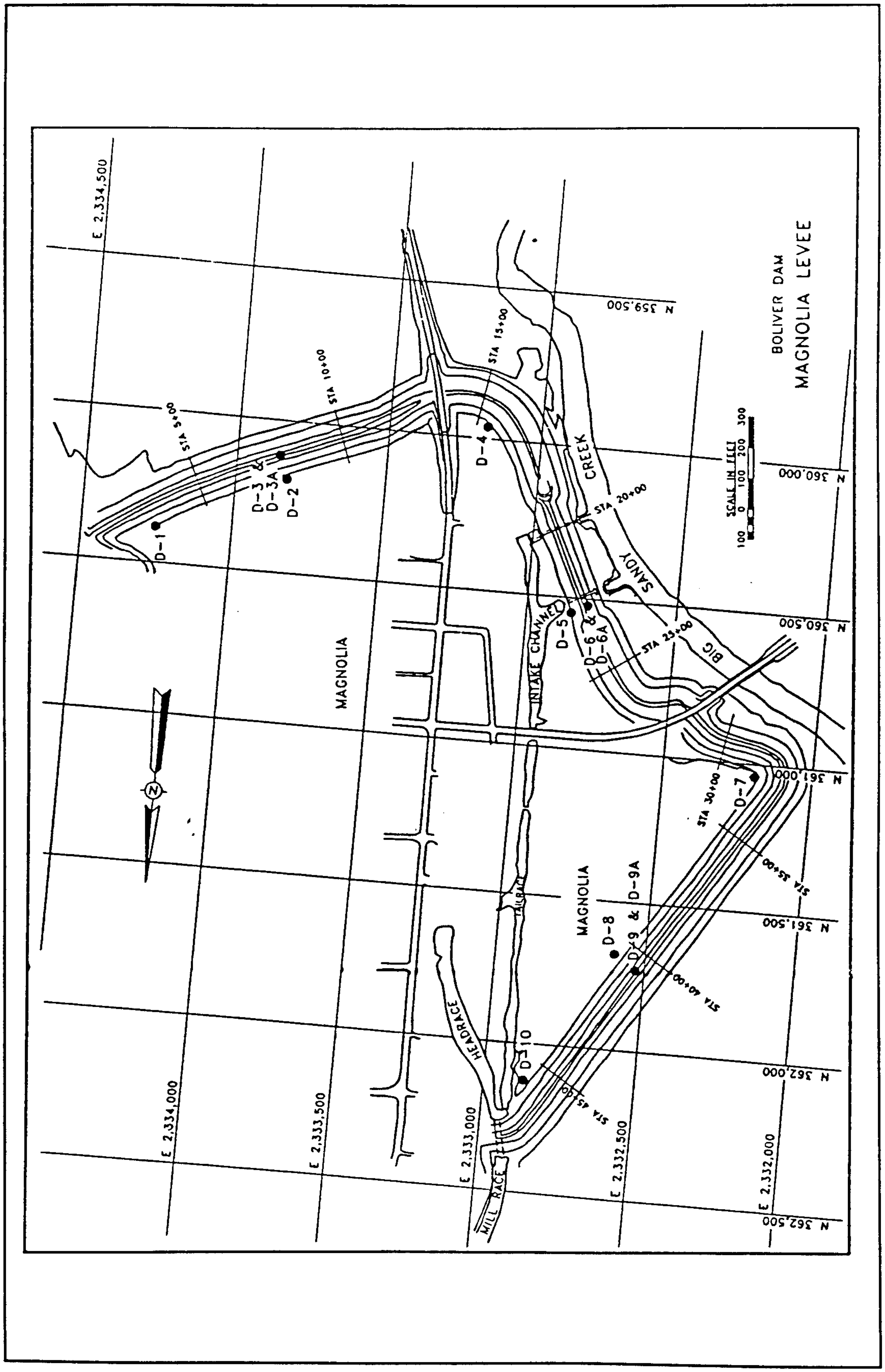

Figure 3. Piezometer locations at Magnolia Levee

4 Analysis

The idealized analyses section and geometrical parameters are presented in Figure 4. Analysis conducted for this study consisted of modeling similar conditions with LEVSEEP, LEVEEMSU, and SEEP, thus providing results from each for comparative investigation. The basic analysis scheme consisted of maintaining the foundation permeability constant and varying the blanket permeability. In case of LEVSEEP and LEVEEMSU, only the vertical blanket coefficient of permeability, k_{by}, and the horizontal foundation coefficient of permeability, k_{fx}, are allowed as input data. For the sake of this study, the k_{by} value was assumed to vary between $1x10^{-3}$ to $1x10^{-6}$ cm/sec while the k_{fx} value was assumed to be constant and equal to $1x10^{-2}$ cm/sec.

Finite Element Analysis

The discretized flow domain is shown in Figure 5. The finite element mesh consisted of 100 quadrilateral elements with the top two rows of elements being 7 ft (2.13 m) in total thickness to represent the top blanket. No levee-through-levee seepage is permitted in this model. The finite element analysis (FEA) parameters are shown in Table 2.

Table 2 **Model Analysis Parameters**
Maximum Pool Elevation = el 976
Length of Top Blanket Riverside = 175 ft
Length of Top Blanket Landside = 2,000 ft
Foundation Layer = 100 ft
Top Blanket = 7 ft

The boundary conditions assumed in the FEA are as follows:

a. No flux through the soil-rock boundary at el 848.2.

b. No flux through nodes at the ground surface under the levee.

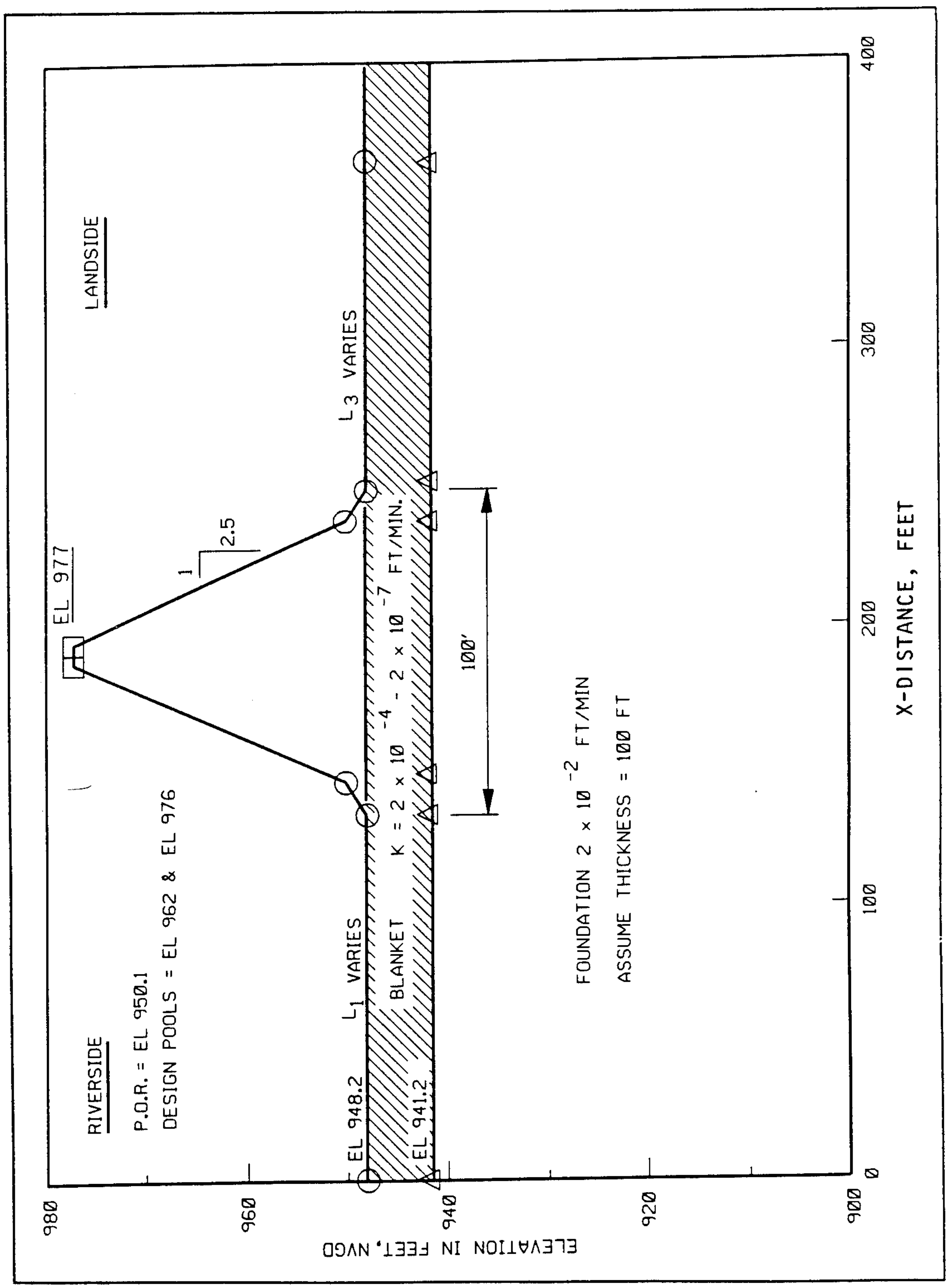

Figure 4. Idealized cross section and geometrical parameters

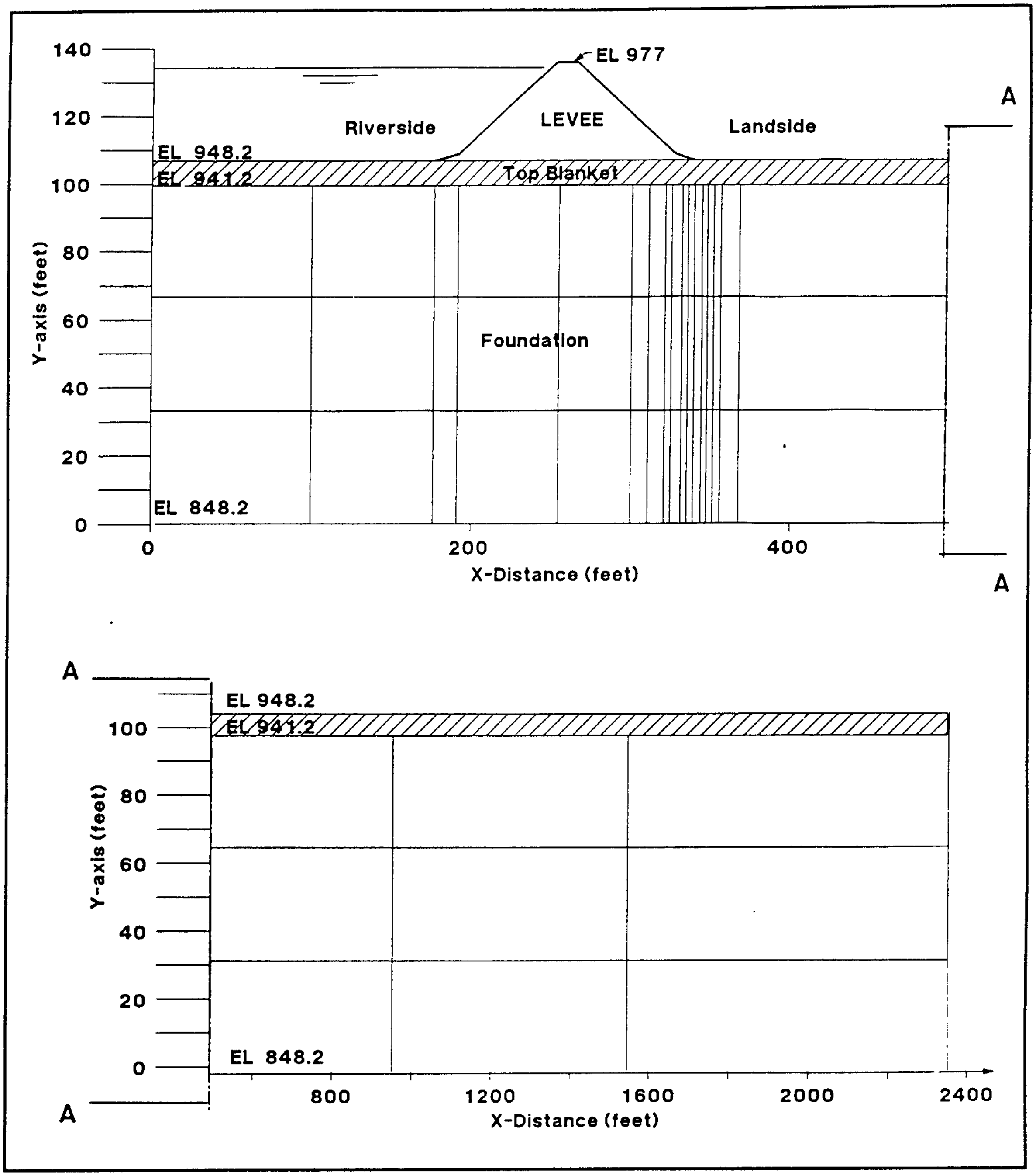

Figure 5. Finite element model and boundary conditions: SEEP

c. Water level landside of the levee at the ground surface.

d. Water level riverside of the levee at el 976.

Analysis Scenarios

Analysis scenarios conducted in this study are summarized in Table 3. Description of each scenario is as follows:

Table 3
Analysis Scenarios and Associated Permeability Values

Analysis Case	Foundation Permeability cm/sec	Blanket Permeability cm/sec
Scenario 1. Simulation of LEVSEEP and LEVEEMSU Results	$k_{fx} = 1x10^{-2}$ $k_{fy} = 1x10^{-7}$	$k_{by} = 1x10^{-3}$ to $1x10^{-6}$ $k_{bx} = k_{by}\ x10^{-5}$
Scenario 2. Anisotropic Permeability Ratios (rk) for Foundation and Blanket of: 1, 10, 100	$k_{fx} = 1x10^{-2}$ $k_{fy} = k_{fx}/rk$	$k_{by} = 1x10^{-3}$ to $1x10^{-6}$ $k_{bx} = k_{by}\ rk$
Scenario 3. Anisotropic Permeability Ratios (rk) of 10 for Foundation only	$k_{fx} = 1x10^{-2}$ $k_{fy} = 1x10^{-3}$	$k_{by} = 1x10^{-3}$ to $1x10^{-6}$ $k_{bx} = k_{by}\ x10^{-5}$
Scenario 4. Anisotropic Permeability Ratios (rk) of 10 for Blanket only	$k_{fx} = 1x10^{-2}$ $k_{fy} = 1x10^{-7}$	$k_{by} = 1x10^{-3}$ to $1x10^{-6}$ $k_{bx} = k_{by}$ x 10

Scenario 1

SEEP analysis of this case assumed the same conditions as those utilized in LEVSEEP and LEVEEMSU. The foundation permeability, k_{fx}, was assumed equal to $1x10^{-2}$ cm/sec. The k_{by} was assumed to vary with k_{fx}/k_{by} ratios of 10, 100, 1,000, and 10,000. For the sake of the FEA, the horizontal blanket permeability, k_{bx}, was assumed equal to k_{by} x 10^{-5}, and the vertical foundation permeability, k_{fy}, was assumed equal to k_{fx} x 10^{-5}.

Scenario 2

This scenario is conducted to investigate the effect of anisotropic conditions on the predicted gradients. An anisotropic ratio (rk) of 10 and 100 (horizontal to vertical) is assumed for both the blanket and the foundation soils. In addition, an isotropic condition was assumed, whereby the permeabilities in the horizontal and vertical direction were assumed equal (or rk= 1). The foundation permeability, k_{fx}, was assumed equal to $1x10^{-2}$ cm/sec. The k_{by} was assumed to vary with k_{fx}/k_{by} ratios of 10, 100, 1,000, and 10,000 utilized in the analysis.

Scenario 3

This case investigates the effect of foundation anisotropic conditions on the predicted gradients. Vertical-only flow is assumed for the blanket while an anisotropic ratio (rk) of 10 is assumed for the foundation soil. The foundation permeability, k_{fx}, was assumed equal to $1x10^{-2}$ cm/sec and k_{by} equal to $1x10^{-3}$ cm/sec. The k_{by} was assumed to vary in order to provide k_{fx} /k_{by} ratios of 10, 100, 1,000, and 10,000.

Scenario 4

This case investigates the effect of blanket anisotropic conditions on the predicted gradients. Horizontal-only flow is assumed for the foundation while an anisotropic ratio (rk) of 10 is assumed for the blanket soil. The foundation permeability, k_{fx}, is assumed equal to $1x10^{-2}$ cm/sec, and k_{by} is varied between $1x10^{-3}$ cm/sec and $1x10^{-6}$ for k_{fx} /k_{by} ratios of 10, 100, 1,000, and 10,000. The k_{bx} is assumed equal to k_{by} x 10.

An independent check of the FEA was conducted using the finite element computer program PCSEEP (Geo-Slope Programming Limited 1987). The mesh used in the "check" analysis consisted of 200 elements and 100 nodes as shown in Figure 6. Boundary conditions were assumed the same as those used in the SEEP model. An example of input files for the computer programs SEEP and PCSEEP is presented in Appendix A. These files contain information defining the model node coordinates, element locations, and boundary conditions.

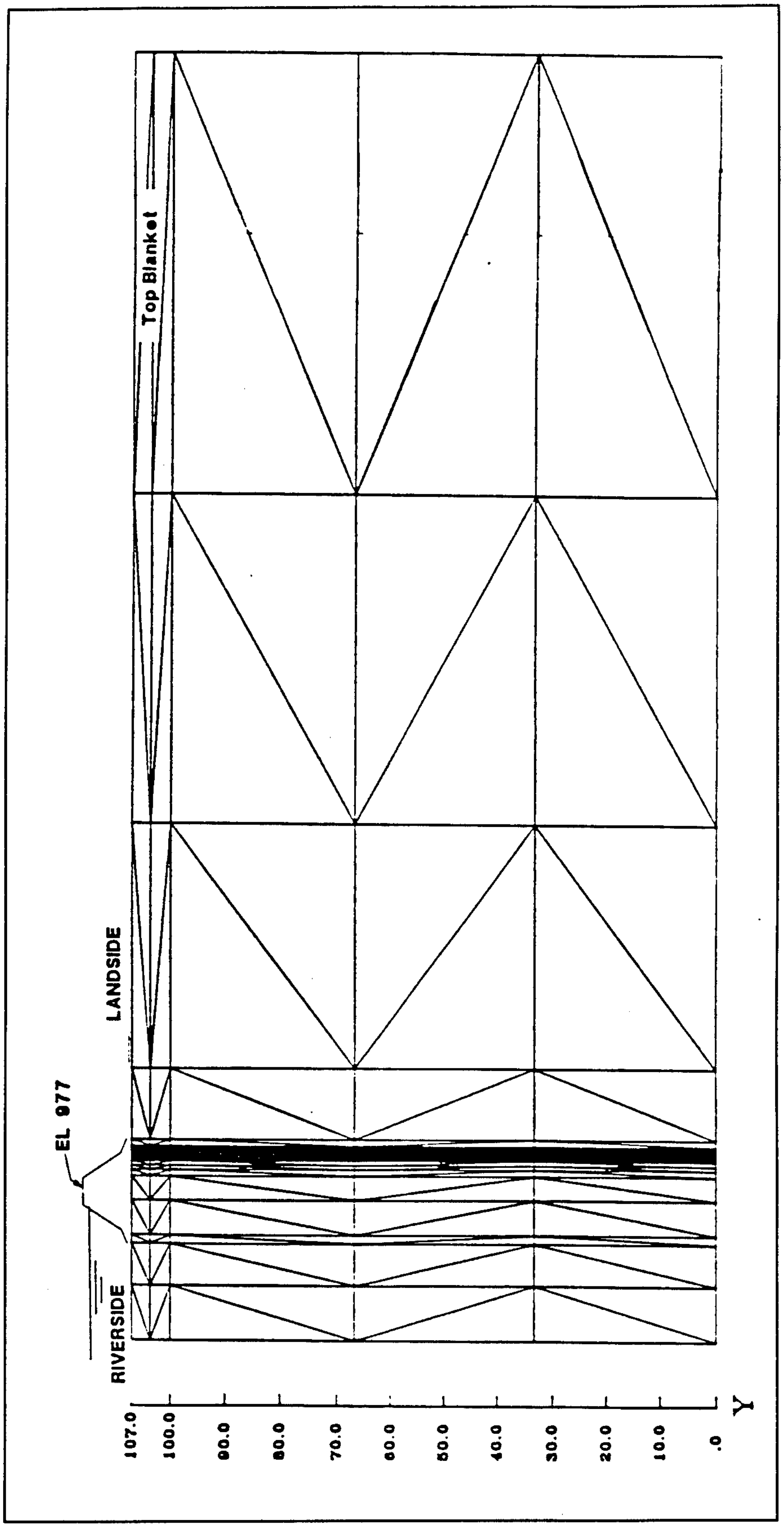

Figure 6. Finite element model and boundary conditions: PCSEEP (Geo-Slope 1987)

5 Results and Discussion

Results of the analysis are presented in Figures 7, 8, and 9. Results obtained from SEEP and PCSEEP were identical for all practical purposes, as shown in Figure 6, and therefore the mesh used in SEEP was deemed adequate. Results for scenarios considered in this study are as follows:

Scenario 1. Comparison to LEVSEEP and LEVEEMSU

Finite element analysis (FEA) of scenario 1 indicated that predictions from LEVSEEP and LEVEEMSU are conservative as evidenced by Figure 7. In general, exit hydraulic gradient (*i*) increased as a function of k_{fx}/k_{by} ratio. In case of k_{fx}/k_{by} ratio equal to 20, *i* from LEVSEEP and LEVEEMSU exceeded 1.0 while *i* predicted from the FEA was on the order of 0.6. The percent difference between *i* from LEVSEEP and LEVEEMSU and that from FEA decreased as the k_{fx}/k_{by} increased.

The FEA was also conducted using the same k_{fx}/k_{by} ratios but with different k_{fx} and k_{by} values. The k_{fx} was assumed equal to $5x10^{-2}$ cm/sec with k_{by} taken such that the ratios of k_{fx}/k_{by} remained 10, 100, 1,000, and 10,000. Results indicated that exit hydraulic gradients from this analysis case have the same magnitudes as those obtained assuming k_{fx} equal to $1x10^{-2}$ cm/sec. With consideration of the boundary conditions and model geometry assumed in the FEA, these results suggest that predicted hydraulic gradients are merely dependent on the k_{fx}/k_{by} ratios.

Scenario 2. Anisotropic Flow Conditions

Analysis results assuming anisotropic flow conditions for the top blanket and the foundation are presented in Figure 8. As previously mentioned, the anisotropic ratio (rk) is defined as the permeability in the horizontal direction to the permeability in the vertical direction. Lower exit hydraulic gradients were obtained for rk of 100 as compared to rk of 1, as shown in Figure 8. In

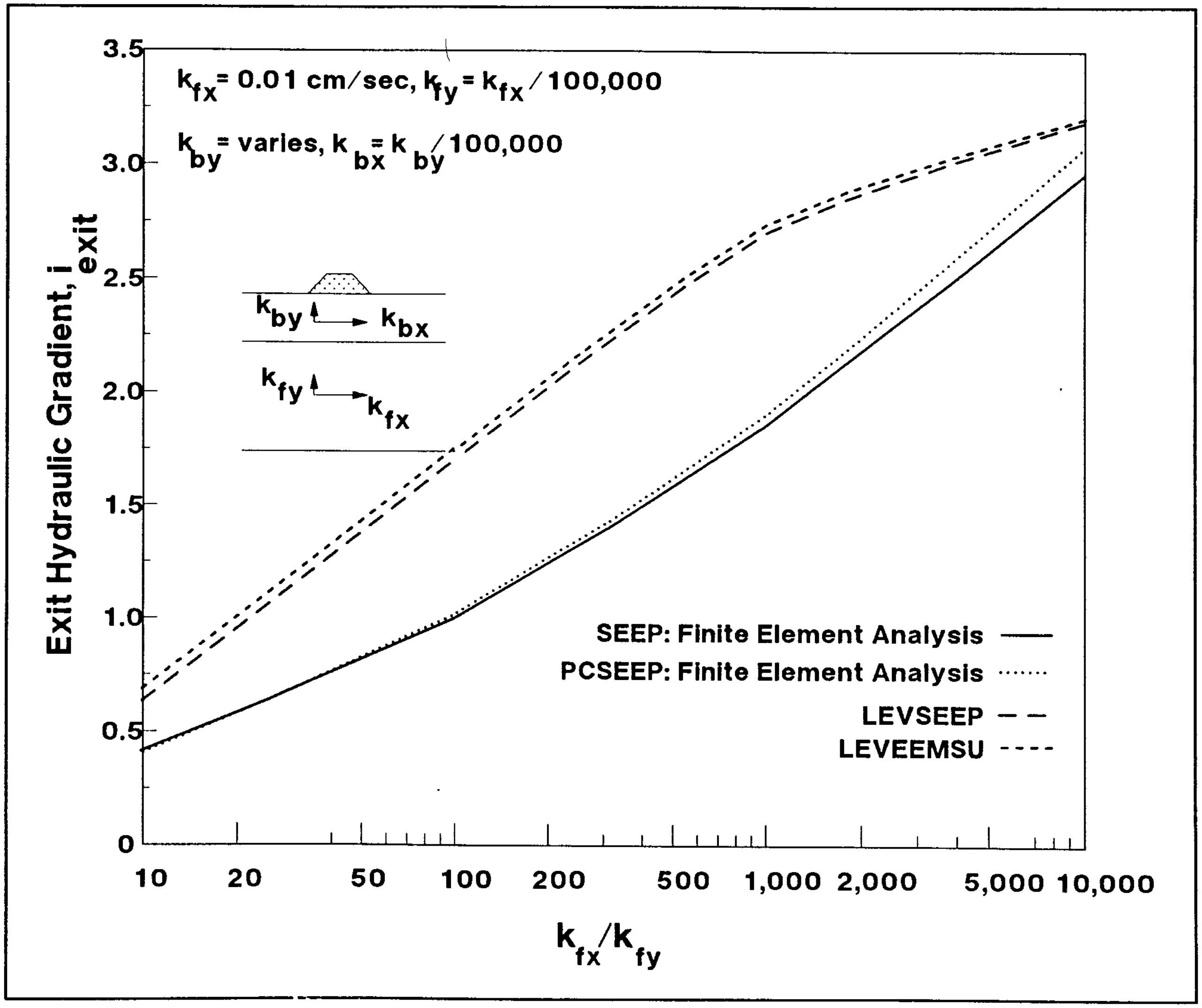

Figure 7. Exit hydraulic gradient as a function of permeability ratio from SEEP, PCSEEP, LEVEEMSU, and LEVSEEP

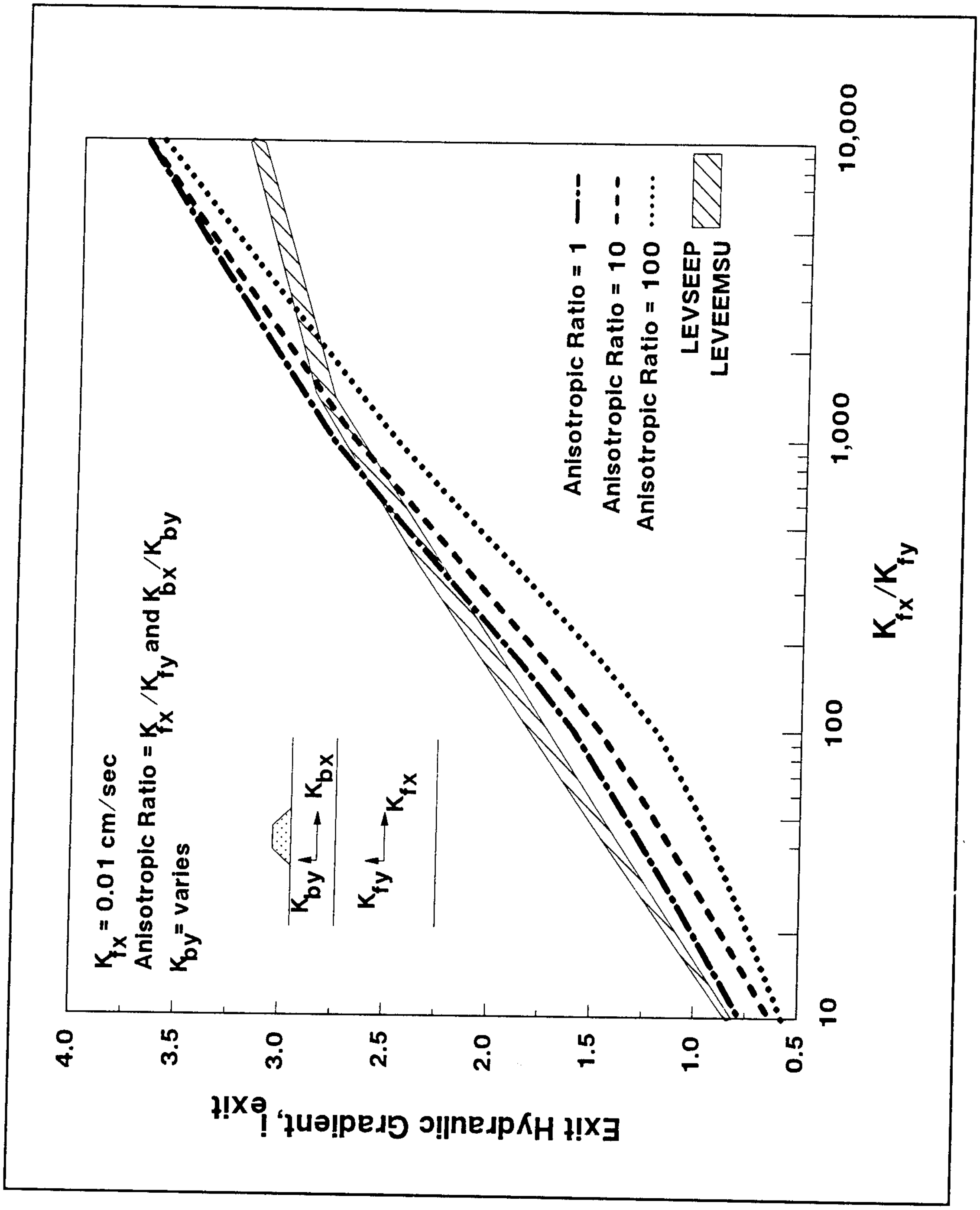

Figure 8. Effect of anisotropic ratio on predicted exit hydraulic gradients

the case of k_{fx}/k_{by} of 50, the value of *i* decreased from 1.3 for rk= 1 to 1.0 for rk= 100. It is of interest to note that the predicted hydraulic gradients, as function of k_{fx}/k_{by}, from the FEA and with rk= 1 assumed closely matched those from LEVSEEP and LEVEEMSU. As the k_{fx}/k_{by} ratios became greater than 2,000, predicted *i* values from the FEA exceeded those from LEVSEEP and LEVEEMSU, as indicated in Figure 8. Nonetheless, for practical purposes, the values of interest are those corresponding to k_{fx}/k_{by} ratios less than 50. This analysis indicated that LEVSEEP and LEVEEMSU would produce unconservative results if field conditions are such that the value of k_{fx}/k_{by} exceeded 2,000 and rk was between 1 and 100.

Scenario 3. Anisotropic Conditions in Foundation Only

Results for this case are shown in Figure 9. These results are based on assuming an rk value of 10 for the foundation with practically no horizontal flow in the blanket. Predicted exit hydraulic gradients in this case were relatively close to those obtained from LEVSEEP and LEVEEMSU. In addition, the predicted variation in *i* values with k_{fx}/k_{by} is similar to that obtained from scenario 2 where rk of 10 was assumed for both the foundation and the blanket. These results indicate that the predicted *i* values are mainly influenced by the anisotropic effect of the foundation layer. Consequently, this observation suggests that anisotropy in permeability of the blanket layer does not greatly affect the predicted exit hydraulic gradients.

Scenario 4. Anisotropic Conditions in Blanket Only

The analysis for this scenario was conducted to confirm the conclusion reached in scenario 3. In this case, an anisotropic ratio of 10 was assumed for the blanket layer, and practically horizontal-only flow was assumed for the foundation layer. Exit hydraulic gradients as a function of k_{fx}/k_{by} are presented in Figure 9. These *i* predictions are similar to those from the FEA presented in Figure 7 where horizontal-only flow is assumed for the foundation and vertical-only flow is assumed for the blanket. Such results indicate that the anisotropic ratio of the blanket layer has insignificant effect on the exit hydraulic gradients as predicted from the flow model presented in this study.

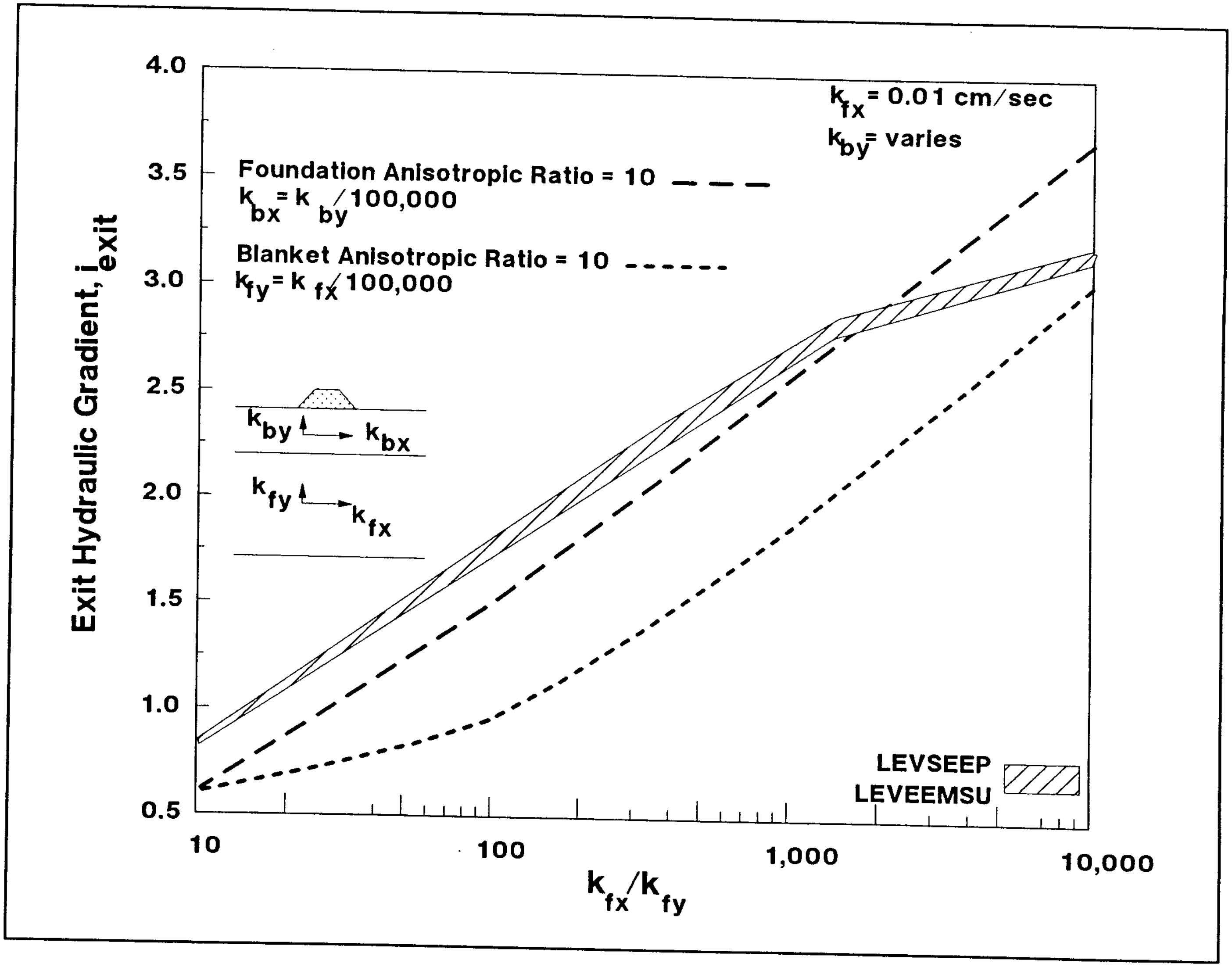

Figure 9. Effect of anisotropic foundation permeability versus anisotropic blanket permeability on the predicted hydraulic gradients

6 Summary and Conclusions

Seepage analyses presented in this study compared results from simplified models implemented in the computer programs LEVSEEP and LEVEEMSU and the two-dimensional finite element model implemented by the computer program SEEP. A prototypical levee section located in Magnolia, Ohio, within the Huntington District of the Corps of Engineers was utilized in this comparative study. Analysis was conducted to illustrate the effect of variations in the ratio of permeability of the foundation (k_f) to the permeability of the blanket (k_b) on the flow predictions, the influence of introducing anisotropic conditions on flow domain, and variation in the predicted hydraulic gradients in relation to the analysis method.

The finite element seepage model consisted of 126 nodes and 200 elements. The boundary conditions assumed in the analysis were similar to those assumed in LEVSEEP and LEVEEMSU and are as follows:

a. No flux through the soil-rock boundary at el 848.2.

b. No flux through nodes at the ground surface under the levee structure.

c. Water level landside of the levee at the ground surface.

d. Water level riverside of the levee at el 976.

Significant difference between results from LEVSEEP and LEVEEMSU and those from the two-dimensional finite element model was obtained. For example, in the case of k_{fx}/k_{by} ratio of 50, which may be representative of the levee section analyzed herein, predicted that *i* from the FEA was on the order of 0.85 and from LEVSEEP and LEVEEMSU was approximately 1.30. In this case, results from the FEA would indicate that no remedial measures are required against piping and excessive uplift while results from LEVSEEP and LEVEEMSU would indicate the need to safeguard against these adverse conditions.

Such difference in magnitude of predicted hydraulic gradients may be attributed to the following factors:

a. Simulation mechanism of horizontal-only flow and vertical-only flow in the finite element model. This simulation was achieved by assuming that the permeability value in the no-flow direction is equal to the permeability value in the flow direction divided by a factor of 100,000. Despite such assumption flow was still taking place in the two-dimensional domain of the finite element model.

b. Assumptions made in LEVSEEP and LEVEEMSU regarding the foundation layer. These programs model the foundation layer as a one-dimensional conduit through which all horizontal flow in this layer will exit through the top blanket. In comparison, two-dimensional modeling in the FEA allows a portion of the flow not to exit through the top blanket but rather continue to travel horizontally through the foundation.

c. The permeability values at the interface between the foundation and the top blanket. The permeability values, in the horizontal and vertical directions, assigned for nodes at the interface between the foundation and the blanket are equal to the average value of the blanket permeability and foundation permeability. In the one-dimensional analysis scheme implemented in LEVEEMSU, the foundation is represented by one row of nodes having the permeability value of the foundation, and the blanket is represented by the second row of nodes having the permeability value of the blanket.

No piezometer data for high-water levels exist to provide a means of verifying the results from the finite element model. However, based on the results obtained from this study, the following conclusions can be advanced:

a. Exit hydraulic gradients predicted from LEVSEEP and LEVEEMSU for the case study presented herein are conservative as compared to those predicted from the finite element model.

b. Exit hydraulic gradients are merely a function of the k_{fx}/k_{by} ratio and not necessarily the value of either k_{fx} or k_{by}.

c. The predicted value of i increased with rk. In general, the percent increase in i with rk was a function of k_{fx}/k_{by}, and it decreased as k_{fx}/k_{by} increased.

d. Predicted i values from the finite element analysis with rk=1 closely matched those from LEVSEEP and LEVEEMSU for k_{fx}/k_{by} less than 2,000.

e. The effect of an anisotropic permeability parameter is most pronounced when this anisotropy is in the foundation layer. Anisotropy in the top blanket has no significant effect on the predicted hydraulic exit gradients.

f. Findings and conclusions reported in this study are specifically for the analysis case and boundary conditions presented in the report. A comprehensive parameter study and investigation of several case histories are needed before conclusions presented herein can be generalized.

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Appendix A
Example of Input Files for SEEP and PCSEEP

EXAMPLE OF INPUT DATA FILE: COMPUTER PROGRAM SEEP

```
Magnolia Levee --- 2-D CONFINED FLOW
1,3,126,200,1
1,0.20000e-2,0.100e-2,0
2,0.400e-6,0.20000e-6,0
3,0,0,0
126
   1 ,   1 ,   0 ,      0 ,  134.8
   2 ,   1 ,   0 ,  33.33 ,  134.8
   3 ,   1 ,   0 ,  66.67 ,  134.8
   4 ,   1 ,   0 ,    100 ,  134.8
   5 ,   1 ,   0 ,  103.5 ,  134.8
   6 ,   1 ,   0 ,    107 ,  134.8
   7 ,   0 , 100 ,      0 ,      0
   8 ,   0 , 100 , 33.333 ,      0
   9 ,   0 , 100 , 66.667 ,      0
  10 ,   0 , 100 ,    100 ,      0
  11 ,   0 , 100 ,  103.5 ,      0
  12 ,   1 , 100 ,    107 ,  134.8
  13 ,   0 , 175 ,      0 ,      0
  14 ,   0 , 175 , 33.333 ,      0
  15 ,   0 , 175 , 66.667 ,      0
  16 ,   0 , 175 ,    100 ,      0
  17 ,   0 , 175 ,  103.5 ,      0
  18 ,   1 , 175 ,    107 ,  134.8
  19 ,   0 , 191 ,      0 ,      0
  20 ,   0 , 191 , 33.333 ,      0
  21 ,   0 , 191 , 66.667 ,      0
  22 ,   0 , 191 ,    100 ,      0
  23 ,   0 , 191 ,  103.5 ,      0
  24 ,   0 , 191 ,    107 ,      0
  25 ,   0 , 255 ,      0 ,      0
  26 ,   0 , 255 , 33.333 ,      0
  27 ,   0 , 255 , 66.667 ,      0
  28 ,   0 , 255 ,    100 ,      0
  29 ,   0 , 255 ,  103.5 ,      0
  30 ,   0 , 255 ,    107 ,      0
  31 ,   0 , 300 ,      0 ,      0
  32 ,   0 , 300 , 33.333 ,      0
  33 ,   0 , 300 , 66.667 ,      0
  34 ,   0 , 300 ,    100 ,      0
  35 ,   0 , 300 ,  103.5 ,      0
  36 ,   0 , 300 ,    107 ,      0
  37 ,   0 , 310 ,      0 ,      0
  38 ,   0 , 310 , 33.333 ,      0
  39 ,   0 , 310 , 66.667 ,      0
  40 ,   0 , 310 ,    100 ,      0
  41 ,   0 , 310 ,  103.5 ,      0
  42 ,   0 , 310 ,    107 ,      0
  43 ,   0 , 320 ,      0 ,      0
  44 ,   0 , 320 , 33.333 ,      0
  45 ,   0 , 320 , 66.667 ,      0
  46 ,   0 , 320 ,    100 ,      0
  47 ,   0 , 320 ,  103.5 ,      0
  48 ,   0 , 320 ,    107 ,      0
  49 ,   0 , 325 ,      0 ,      0
  50 ,   0 , 325 , 33.333 ,      0
  51 ,   0 , 325 , 66.667 ,      0
  52 ,   0 , 325 ,    100 ,      0
  53 ,   0 , 325 ,  103.5 ,      0
  54 ,   0 , 325 ,    107 ,      0
  55 ,   0 , 331 ,      0 ,      0
  56 ,   0 , 331 , 33.333 ,      0
  57 ,   0 , 331 , 66.667 ,      0
  58 ,   0 , 331 ,    100 ,      0
  59 ,   0 , 331 ,  103.5 ,      0
  60 ,   0 , 331 ,    107 ,      0
  61 ,   0 , 335 ,      0 ,      0
  62 ,   0 , 335 , 33.333 ,      0
  63 ,   0 , 335 , 66.667 ,      0
  64 ,   0 , 335 ,    100 ,      0
  65 ,   0 , 335 ,  103.5 ,      0
```

```
 66 ,    0 ,   335 ,    107 ,     0
 67 ,    0 ,   339 ,      0 ,     0
 68 ,    0 ,   339 , 33.333 ,     0
 69 ,    0 ,   339 , 66.667 ,     0
 70 ,    0 ,   339 ,    100 ,     0
 71 ,    0 ,   339 ,  103.5 ,     0
 72 ,    0 ,   339 ,    107 ,     0
 73 ,    0 ,   343 ,      0 ,     0
 74 ,    0 ,   343 , 33.333 ,     0
 75 ,    0 ,   343 , 66.667 ,     0
 76 ,    0 ,   343 ,    100 ,     0
 77 ,    0 ,   343 ,  103.5 ,     0
 78 ,    0 ,   343 ,    107 ,     0
 79 ,    0 ,   347 ,      0 ,     0
 80 ,    0 ,   347 , 33.333 ,     0
 81 ,    0 ,   347 , 66.667 ,     0
 82 ,    0 ,   347 ,    100 ,     0
 83 ,    0 ,   347 ,  103.5 ,     0
 84 ,    1 ,   347 ,    107 ,     0
 85 ,    0 ,   351 ,      0 ,     0
 86 ,    0 ,   351 , 33.333 ,     0
 87 ,    0 ,   351 , 66.667 ,     0
 88 ,    0 ,   351 ,    100 ,     0
 89 ,    0 ,   351 ,  103.5 ,     0
 90 ,    0 ,   351 ,    107 ,     0
 91 ,    0 ,   355 ,      0 ,     0
 92 ,    0 ,   355 , 33.333 ,     0
 93 ,    0 ,   355 , 66.667 ,     0
 94 ,    0 ,   355 ,    100 ,     0
 95 ,    0 ,   355 ,  103.5 ,     0
 96 ,    1 ,   355 ,    107 ,   107
 97 ,    0 ,   367 ,      0 ,     0
 98 ,    0 ,   367 , 33.333 ,     0
 99 ,    0 ,   367 , 66.667 ,     0
100 ,    0 ,   367 ,    100 ,     0
101 ,    0 ,   367 ,  103.5 ,     0
102 ,    1 ,   367 ,    107 ,   107
103 ,    0 ,   497 ,      0 ,     0
104 ,    0 ,   497 , 33.333 ,     0
105 ,    0 ,   497 , 66.667 ,     0
106 ,    0 ,   497 ,    100 ,     0
107 ,    0 ,   497 ,  103.5 ,     0
108 ,    1 ,   497 ,    107 ,   107
109 ,    0 ,   947 ,      0 ,     0
110 ,    0 ,   947 , 33.333 ,     0
111 ,    0 ,   947 , 66.667 ,     0
112 ,    0 ,   947 ,    100 ,     0
113 ,    0 ,   947 ,  103.5 ,     0
114 ,    1 ,   947 ,    107 ,   107
115 ,    0 ,  1547 ,      0 ,     0
116 ,    0 ,  1547 , 33.333 ,     0
117 ,    0 ,  1547 , 66.667 ,     0
118 ,    0 ,  1547 ,    100 ,     0
119 ,    0 ,  1547 ,  103.5 ,     0
120 ,    1 ,  1547 ,    107 ,   107
121 ,    0 ,  2347 ,      0 ,     0
122 ,    0 ,  2347 ,  33.33 ,     0
123 ,    0 ,  2347 ,  66.67 ,     0
124 ,    0 ,  2347 ,    100 ,     0
125 ,    0 ,  2347 ,  103.5 ,     0
126 ,    1 ,  2347 ,    107 ,   107
200
  1 ,    8 ,     1 ,      7 ,     0 ,     1 ,
  2 ,    8 ,     2 ,      1 ,     0 ,     1 ,
  3 ,    8 ,     3 ,      2 ,     0 ,     1 ,
  4 ,    8 ,     9 ,      3 ,     0 ,     1 ,
  5 ,   10 ,     3 ,      9 ,     0 ,     1 ,
  6 ,   10 ,     4 ,      3 ,     0 ,     1 ,
  7 ,   10 ,     5 ,      4 ,     0 ,     2 ,
  8 ,   10 ,    11 ,      5 ,     0 ,     2 ,
  9 ,   12 ,     5 ,     11 ,     0 ,     2 ,
 10 ,   12 ,     6 ,      5 ,     0 ,     2 ,
 11 ,   14 ,     7 ,     13 ,     0 ,     1 ,
```

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15 , 16 ,  9 , 15 , 0 , 1 ,
16 , 16 , 10 ,  9 , 0 , 1 ,
17 , 16 , 11 , 10 , 0 , 2 ,
18 , 16 , 17 , 11 , 0 , 2 ,
19 , 18 , 11 , 17 , 0 , 2 ,
20 , 18 , 12 , 11 , 0 , 2 ,
21 , 20 , 13 , 19 , 0 , 1 ,
22 , 20 , 14 , 13 , 0 , 1 ,
23 , 20 , 15 , 14 , 0 , 1 ,
24 , 20 , 21 , 15 , 0 , 1 ,
25 , 22 , 15 , 21 , 0 , 1 ,
26 , 22 , 16 , 15 , 0 , 1 ,
27 , 22 , 17 , 16 , 0 , 2 ,
28 , 22 , 23 , 17 , 0 , 2 ,
29 , 24 , 17 , 23 , 0 , 2 ,
30 , 24 , 18 , 17 , 0 , 2 ,
31 , 26 , 19 , 25 , 0 , 1 ,
32 , 26 , 20 , 19 , 0 , 1 ,
33 , 26 , 21 , 20 , 0 , 1 ,
34 , 26 , 27 , 21 , 0 , 1 ,
35 , 28 , 21 , 27 , 0 , 1 ,
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38 , 28 , 29 , 23 , 0 , 2 ,
39 , 30 , 23 , 29 , 0 , 2 ,
40 , 30 , 24 , 23 , 0 , 2 ,
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42 , 32 , 26 , 25 , 0 , 1 ,
43 , 32 , 27 , 26 , 0 , 1 ,
44 , 32 , 33 , 27 , 0 , 1 ,
45 , 34 , 27 , 33 , 0 , 1 ,
46 , 34 , 28 , 27 , 0 , 1 ,
47 , 34 , 29 , 28 , 0 , 2 ,
48 , 34 , 35 , 29 , 0 , 2 ,
49 , 36 , 29 , 35 , 0 , 2 ,
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51 , 38 , 31 , 37 , 0 , 1 ,
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53 , 38 , 33 , 32 , 0 , 1 ,
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55 , 40 , 33 , 39 , 0 , 1 ,
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58 , 40 , 41 , 35 , 0 , 2 ,
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60 , 42 , 36 , 35 , 0 , 2 ,
61 , 44 , 37 , 43 , 0 , 1 ,
62 , 44 , 38 , 37 , 0 , 1 ,
63 , 44 , 39 , 38 , 0 , 1 ,
64 , 44 , 45 , 39 , 0 , 1 ,
65 , 46 , 39 , 45 , 0 , 1 ,
66 , 46 , 40 , 39 , 0 , 1 ,
67 , 46 , 41 , 40 , 0 , 2 ,
68 , 46 , 47 , 41 , 0 , 2 ,
69 , 48 , 41 , 47 , 0 , 2 ,
70 , 48 , 42 , 41 , 0 , 2 ,
71 , 50 , 43 , 49 , 0 , 1 ,
72 , 50 , 44 , 43 , 0 , 1 ,
73 , 50 , 45 , 44 , 0 , 1 ,
74 , 50 , 51 , 45 , 0 , 1 ,
75 , 52 , 45 , 51 , 0 , 1 ,
76 , 52 , 46 , 45 , 0 , 1 ,
77 , 52 , 47 , 46 , 0 , 2 ,
78 , 52 , 53 , 47 , 0 , 2 ,
79 , 54 , 47 , 53 , 0 , 2 ,
80 , 54 , 48 , 47 , 0 , 2 ,
81 , 56 , 49 , 55 , 0 , 1 ,
82 , 56 , 50 , 49 , 0 , 1 ,
83 , 56 , 51 , 50 , 0 , 1 ,
84 , 56 , 57 , 51 , 0 , 1 ,
```

85 ,	58 ,	51 ,	57 ,	0 ,	1 ,
86 ,	58 ,	52 ,	51 ,	0 ,	1 ,
87 ,	58 ,	53 ,	52 ,	0 ,	2 ,
88 ,	58 ,	59 ,	53 ,	0 ,	2 ,
89 ,	60 ,	53 ,	59 ,	0 ,	2 ,
90 ,	60 ,	54 ,	53 ,	0 ,	2 ,
91 ,	62 ,	55 ,	61 ,	0 ,	1 ,
92 ,	62 ,	56 ,	55 ,	0 ,	1 ,
93 ,	62 ,	57 ,	56 ,	0 ,	1 ,
94 ,	62 ,	63 ,	57 ,	0 ,	1 ,
95 ,	64 ,	57 ,	63 ,	0 ,	1 ,
96 ,	64 ,	58 ,	57 ,	0 ,	1 ,
97 ,	64 ,	59 ,	58 ,	0 ,	2 ,
98 ,	64 ,	65 ,	59 ,	0 ,	2 ,
99 ,	66 ,	59 ,	65 ,	0 ,	2 ,
100 ,	66 ,	60 ,	59 ,	0 ,	2 ,
101 ,	68 ,	61 ,	67 ,	0 ,	1 ,
102 ,	68 ,	62 ,	61 ,	0 ,	1 ,
103 ,	68 ,	63 ,	62 ,	0 ,	1 ,
104 ,	68 ,	69 ,	63 ,	0 ,	1 ,
105 ,	70 ,	63 ,	69 ,	0 ,	1 ,
106 ,	70 ,	64 ,	63 ,	0 ,	1 ,
107 ,	70 ,	65 ,	64 ,	0 ,	2 ,
108 ,	70 ,	71 ,	65 ,	0 ,	2 ,
109 ,	72 ,	65 ,	71 ,	0 ,	2 ,
110 ,	72 ,	66 ,	65 ,	0 ,	2 ,
111 ,	74 ,	67 ,	73 ,	0 ,	1 ,
112 ,	74 ,	68 ,	67 ,	0 ,	1 ,
113 ,	74 ,	69 ,	68 ,	0 ,	1 ,
114 ,	74 ,	75 ,	69 ,	0 ,	1 ,
115 ,	76 ,	69 ,	75 ,	0 ,	1 ,
116 ,	76 ,	70 ,	69 ,	0 ,	1 ,
117 ,	76 ,	71 ,	70 ,	0 ,	2 ,
118 ,	76 ,	77 ,	71 ,	0 ,	2 ,
119 ,	78 ,	71 ,	77 ,	0 ,	2 ,
120 ,	78 ,	72 ,	71 ,	0 ,	2 ,
121 ,	80 ,	73 ,	79 ,	0 ,	1 ,
122 ,	80 ,	74 ,	73 ,	0 ,	1 ,
123 ,	80 ,	75 ,	74 ,	0 ,	1 ,
124 ,	80 ,	81 ,	75 ,	0 ,	1 ,
125 ,	82 ,	75 ,	81 ,	0 ,	1 ,
126 ,	82 ,	76 ,	75 ,	0 ,	1 ,
127 ,	82 ,	77 ,	76 ,	0 ,	2 ,
128 ,	82 ,	83 ,	77 ,	0 ,	2 ,
129 ,	84 ,	77 ,	83 ,	0 ,	2 ,
130 ,	84 ,	78 ,	77 ,	0 ,	2 ,
131 ,	86 ,	79 ,	85 ,	0 ,	1 ,
132 ,	86 ,	80 ,	79 ,	0 ,	1 ,
133 ,	86 ,	81 ,	80 ,	0 ,	1 ,
134 ,	86 ,	87 ,	81 ,	0 ,	1 ,
135 ,	88 ,	81 ,	87 ,	0 ,	1 ,
136 ,	88 ,	82 ,	81 ,	0 ,	1 ,
137 ,	88 ,	83 ,	82 ,	0 ,	2 ,
138 ,	88 ,	89 ,	83 ,	0 ,	2 ,
139 ,	90 ,	83 ,	89 ,	0 ,	2 ,
140 ,	90 ,	84 ,	83 ,	0 ,	2 ,
141 ,	92 ,	85 ,	91 ,	0 ,	1 ,
142 ,	92 ,	86 ,	85 ,	0 ,	1 ,
143 ,	92 ,	87 ,	86 ,	0 ,	1 ,
144 ,	92 ,	93 ,	87 ,	0 ,	1 ,
145 ,	94 ,	87 ,	93 ,	0 ,	1 ,
146 ,	94 ,	88 ,	87 ,	0 ,	1 ,
147 ,	94 ,	89 ,	88 ,	0 ,	2 ,
148 ,	94 ,	95 ,	89 ,	0 ,	2 ,
149 ,	96 ,	89 ,	95 ,	0 ,	2 ,
150 ,	96 ,	90 ,	89 ,	0 ,	2 ,
151 ,	98 ,	91 ,	97 ,	0 ,	1 ,
152 ,	98 ,	92 ,	91 ,	0 ,	1 ,
153 ,	98 ,	93 ,	92 ,	0 ,	1 ,
154 ,	98 ,	99 ,	93 ,	0 ,	1 ,
155 ,	100 ,	93 ,	99 ,	0 ,	1 ,
156 ,	100 ,	94 ,	93 ,	0 ,	1 ,
157 ,	100 ,	95 ,	94 ,	0 ,	2 ,

158 ,	100 ,	101 ,	95 ,	0 ,	2 ,
159 ,	102 ,	95 ,	101 ,	0 ,	2 ,
160 ,	102 ,	96 ,	95 ,	0 ,	2 ,
161 ,	104 ,	97 ,	103 ,	0 ,	1 ,
162 ,	104 ,	98 ,	97 ,	0 ,	1 ,
163 ,	104 ,	99 ,	98 ,	0 ,	1 ,
164 ,	104 ,	105 ,	99 ,	0 ,	1 ,
165 ,	106 ,	99 ,	105 ,	0 ,	1 ,
166 ,	106 ,	100 ,	99 ,	0 ,	1 ,
167 ,	106 ,	101 ,	100 ,	0 ,	2 ,
168 ,	106 ,	107 ,	101 ,	0 ,	2 ,
169 ,	108 ,	101 ,	107 ,	0 ,	2 ,
170 ,	108 ,	102 ,	101 ,	0 ,	2 ,
171 ,	110 ,	103 ,	109 ,	0 ,	1 ,
172 ,	110 ,	104 ,	103 ,	0 ,	1 ,
173 ,	110 ,	105 ,	104 ,	0 ,	1 ,
174 ,	110 ,	111 ,	105 ,	0 ,	1 ,
175 ,	112 ,	105 ,	111 ,	0 ,	1 ,
176 ,	112 ,	106 ,	105 ,	0 ,	1 ,
177 ,	112 ,	107 ,	106 ,	0 ,	2 ,
178 ,	112 ,	113 ,	107 ,	0 ,	2 ,
179 ,	114 ,	107 ,	113 ,	0 ,	2 ,
180 ,	114 ,	108 ,	107 ,	0 ,	2 ,
181 ,	116 ,	109 ,	115 ,	0 ,	1 ,
182 ,	116 ,	110 ,	109 ,	0 ,	1 ,
183 ,	116 ,	111 ,	110 ,	0 ,	1 ,
184 ,	116 ,	117 ,	111 ,	0 ,	1 ,
185 ,	118 ,	111 ,	117 ,	0 ,	1 ,
186 ,	118 ,	112 ,	111 ,	0 ,	1 ,
187 ,	118 ,	113 ,	112 ,	0 ,	2 ,
188 ,	118 ,	119 ,	113 ,	0 ,	2 ,
189 ,	120 ,	113 ,	119 ,	0 ,	2 ,
190 ,	120 ,	114 ,	113 ,	0 ,	2 ,
191 ,	122 ,	115 ,	121 ,	0 ,	1 ,
192 ,	122 ,	116 ,	115 ,	0 ,	1 ,
193 ,	122 ,	117 ,	116 ,	0 ,	1 ,
194 ,	122 ,	123 ,	117 ,	0 ,	1 ,
195 ,	124 ,	117 ,	123 ,	0 ,	1 ,
196 ,	124 ,	118 ,	117 ,	0 ,	1 ,
197 ,	124 ,	119 ,	118 ,	0 ,	2 ,
198 ,	124 ,	125 ,	119 ,	0 ,	2 ,
199 ,	125 ,	120 ,	119 ,	0 ,	2 ,
200 ,	125 ,	126 ,	120 ,	0 ,	2 ,

EXAMPLE Of INPUT DATA FILE: COMPUTER PROGRAM PCSEEP

```
TITLE
     Magnolia Levee
     1                 = TRIAL NUMBER
     11/20/92          = DATE

CONTROL
               1,      = TYPE OF ANALYSIS(1=S-STATE, 2=TRANSIENT)
               1,      = ITERATION METHOD (1=R.SUB., 2=SECANT)
UNITS
               2,      = LENGTH UNITS (1=METRES, 2=FEET)
               2,      = TIME UNITS (1=SEC,2=MIN,3=HR,4=DAY,5=YEAR)
CONVERGE
              20,      = MAXIMUM NUMBER OF ITERATIONS
             5.0,      = CONVERG. TOLERANCE BY HEAD (IN %)
            10.0,      = CONVERG. TOLERANCE BY PERM.(IN %)
SOIL       ,   2
    1,    .2000E+01,       1.0,       .00,     1,    0,
    2,    2.000E-01,       1.0,     90.00,     1,    0,
BOUNDARY   ,   6
    1,    5,     2,    1,        = START NODE, END NODE, BNDRY TYPE
             .1347000E+03,  = BNDRY VALUE
    6,   18,     2,    1,        = START NODE, END NODE, BNDRY TYPE
             .1347000E+03,  = BNDRY VALUE
    7,  121,     1,    1,        = START NODE, END NODE, BNDRY TYPE
             .0000000E+00,  = BNDRY VALUE
   24,   90,     1,    1,        = START NODE, END NODE, BNDRY TYPE
             .0000000E+00,  = BNDRY VALUE
   90,  120,     2,    1,        = START NODE, END NODE, BNDRY TYPE
             .1070000E+03,  = BNDRY VALUE
  122,  126,     1,    1,        = START NODE, END NODE, BNDRY TYPE
             .0000000E+00,  = BNDRY VALUE
RBOUNDARY ,    0
FLUX      ,    0
NODE      ,  126
     1,       .000,       .000,  .0000000E+00,     0,
     2,       .000,     33.330,  .0000000E+00,     0,
     3,       .000,     66.670,  .0000000E+00,     0,
     4,       .000,    100.000,  .0000000E+00,     0,
     5,       .000,    103.500,  .0000000E+00,     0,
     6,       .000,    107.000,  .0000000E+00,     0,
     7,    100.000,       .000,  .0000000E+00,     0,
     8,    100.000,     33.333,  .0000000E+00,     0,
     9,    100.000,     66.667,  .0000000E+00,     0,
    10,    100.000,    100.000,  .0000000E+00,     0,
    11,    100.000,    103.500,  .0000000E+00,     0,
    12,    100.000,    107.000,  .0000000E+00,     0,
    13,    175.000,       .000,  .0000000E+00,     0,
    14,    175.000,     33.333,  .0000000E+00,     0,
    15,    175.000,     66.667,  .0000000E+00,     0,
    16,    175.000,    100.000,  .0000000E+00,     0,
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    18,    175.000,    107.000,  .0000000E+00,     0,
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The computer programs for levee underseepage analyses-LEVEEMSU (finite difference), LEVSEEP (closed form), and SEEP (finite element)-were used to analyze a levee and foundation section described in this report. Results presented in this study illustrate the effect of variations in the ratio of permeability of the foundation (k_f) to the permeability of the blanket (k_b) on the flow predictions, the influence of introducing anisotropic conditions on flow domain, and variation in the predicted hydraulic gradients in relation to the analysis method. Analysis results are reported in terms of landside exit hydraulic gradients and permeability ratios.

14. SUBJECT TERMS

Blanket permeability	Foundation	Underseepage
Exit gradient	Levee	
Flow	Permeability	

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